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Observations on Changing Residential Design Conditions and Recommendations for Register Assessment for the High Performance Home

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ABSTRACT

There are a number of significant differences between the conditions for which registers have traditionally been designed and tested and the conditions in today's high performance house. This paper examines many of these differences through field evaluation studies and test chamber experiments. Finally, it proposes a new set of topics, the objective of which is to develop a set of register performance measures that are more appropriate to high performance residential applications.

INTRODUCTION

Most research on register performance and occupant comfort has been assumed to apply to buildings constructed to relatively non-demanding thermal performance standards or primarily for commercial applications (Chen et al. 1992; Fountain et al. 1994; IBACOS 2000; Int-Hout 1983; Jackman 1991; Johansson 1995; Nelson 1989; Tanabe and Kimura 1989; Tavakkol et al. 1994). Little research on this topic has been done specifically in the residential sector. The result has been forced-air distribution systems based on old construction methods being installed in new homes with much better thermal performance. The development of technology in the area of residential forced-air distribution systems has not kept pace with the energy efficiency improvements in residential construction. Today's high performance (thermal) residential designs, including homes designed to the most current energy codes, present a very different set of application conditions.

1. Thermal losses are reduced (particularly radiant gains/losses at windows).
2. Radiant asymmetry is thus reduced.
3. With tighter houses, drafts are greatly reduced.
4. With lower thermal loads, heating and cooling air volumes are much reduced (Figure 1).
5. Mechanical ventilation and air circulation are often used.
6. Control of humidity has grown in importance.
7. Variable-speed equipment and/or zoning systems introduce a new level of airflow variability.
8. Blockage of floor, baseboard, or low-wall registers can render the register useless.

Registers are thus called upon to perform under a wide range of conditions. Discharge airflows may vary from full flow at cooling conditions to a greatly reduced flow at ventilating conditions. Or, if a zoning system is installed, flow may

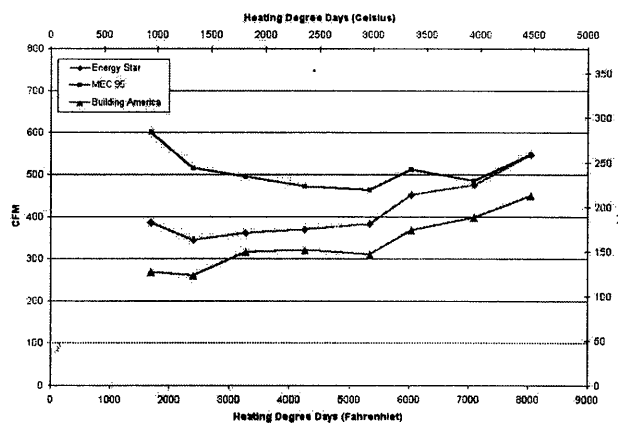

Figure 1 *Heating design airflows.*

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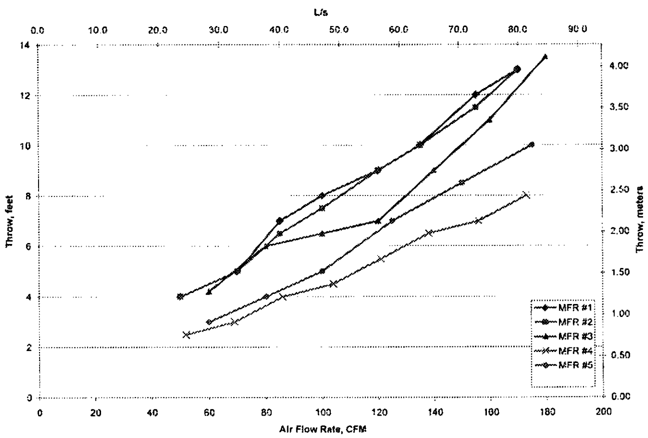


Figure 2 *Discharge performance of 4 × 10 (101.6 × 254 mm) floor registers.*

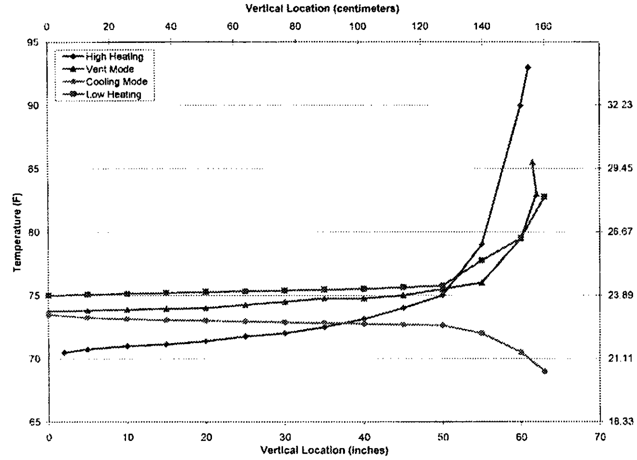


Figure 3 *Thermal stratification near diffuser.*

vary from somewhat above design maximum when all other zone dampers are closed to greatly reduced when all zones are open.

These wide-ranging flows are accomplished at varying temperatures (which affect buoyancy of the discharge stream) from cooling to heating to untempered (ventilation mixing). Note also that with some of the best furnaces and air conditioners, either heating or cooling may be at variable speed or variable temperature. Consider further that heat pump discharge for heating is generally at a lower temperature than the supply discharge from a gas furnace.

Another major variable in the application of registers is location. Some registers, notably floor and baseboard registers and stamped metal center ceiling registers, are typically used only in one location. However, there are many, particularly the adjustable blade registers, that may be used anywhere on the wall or ceiling plane.

Tabular register design data from manufacturers typically present performance data for a free, isothermal jet under one, or a very limited, set of conditions. This does not cover the variety of conditions for which registers must be designed in today's high performance house. Furthermore, most register testing and test procedures are scaled to commercial room sizes, not residential; thus wall effects may not be satisfactorily accounted for. In residential manufacturers' data, registers that are considered the same often have considerably different performance capabilities. The tabulation of the performance of nominal 4 ×10 (101.6 × 254 mm) floor registers (Figure 2) illustrates this problem.

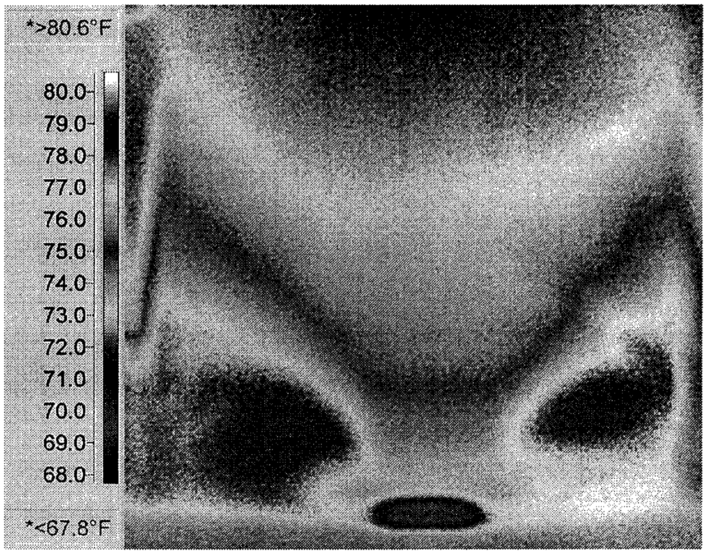
To develop a better understanding of these "old" versus "new" system design issues, several investigations were undertaken. These included test and evaluation work conducted with homes in the field and in a laboratory test room designed to represent residential conditions.

FIELD TESTS

The first indication that a new approach to room air distribution might be appropriate was seen in a Lab Home constructed in Pittsburgh, Penn. In this "better home" that had a greatly reduced thermal load, a design was introduced that concentrated ductwork along the centerline of the house with most room diffusers mounted in the ceiling near the inside wall. A high quality commercial strip diffuser was used that discharged air across the ceiling to the outside wall. The airstream was held to the ceiling by the "Coanda effect" and carried across the room and down the outside wall. The system operated with the reduced airflows of the low-load house. Comfort conditions in the house were excellent. The pattern of discharge airflow was measured using a thermal screen and infrared camera (Figure 3) with the screen set up directly on the axis of diffuser discharge. Figure 3 demonstrates that the ceiling diffuser creates a well-defined jet that attaches to the ceiling under all flow conditions. Large temperature differences are limited to the area near the ceiling and largely disappear by the time the jet reaches the window (Anderson 1996). This positive performance allowed several conclusions:

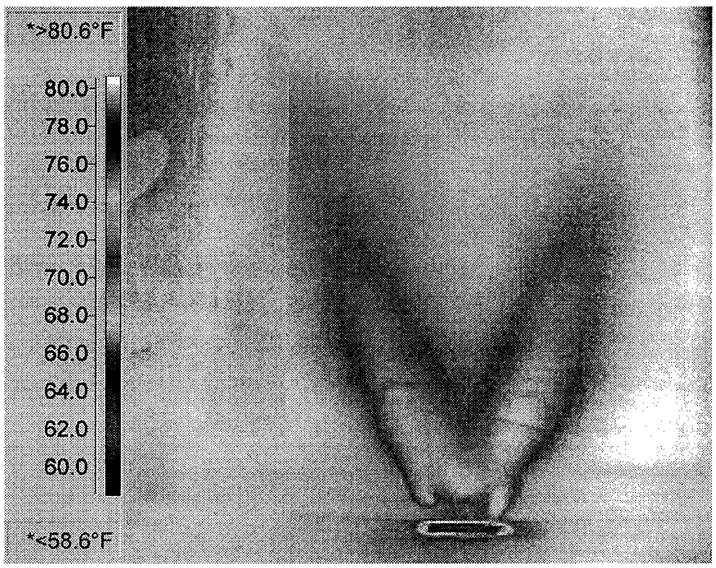
1. It is possible to achieve centerline duct designs using high-quality diffusers.
2. It would be desirable to achieve this performance using less expensive, residential grade diffusers.
3. It would be desirable also to find a satisfactory design that was based on the use of high sidewall diffusers so that ducts would not be needed in the attic (to reduce thermal loss).
4. Overall duct length can be reduced; thus, duct losses are reduced and static pressure may be available to provide good air mixing in the room.

To better characterize the performance of current, industry standard, diffuser selection and placement, a study was conducted on two new homes in Indianapolis, Ind. (IBACOS 2000). These houses, of typical new construction quality (not Building America quality), had traditionally sized mechanical systems. Each had significant duct leakage but was supplying what was considered to be "acceptable" air volumes to the occupied rooms.



Reference:	House 1
Image:	5
Diffuser:	4 x 10 (102 x 254 mm), floor, fixed-vane, 2-way, opposed blade
Airflow:	103 cfm (49 L/s), fan on high, register full open
Temps:	Supply air – 58°F (14°C) Room air- 76°F (24°C)
Elapsed Time:	10 minutes into cooling cycle
Notes:	Vertical throw is insufficient to mix cold supply air with warm room air in the upper part of the occupied zone.

Figure 4 *House 1, full flow cooling.*



Reference:	House 2
Image:	4
Diffuser:	4 x 10 (102 x 254 mm), floor, fixed-vane, 2-way, opposed blade
Airflow:	125 cfm (59 L/s), zone damper full open, others closed, register full open
Temps:	Supply air – 56°F (14°C) Room air- 76°F (24°C)
Elapsed Time:	17 minutes into cooling cycle
Notes:	Throw and distribution are well developed at a diffuser face velocity of 700 fpm (3.56 m/s), but volume is too much for most rooms

Figure 5 *House 2, full flow cooling.*

Evaluation of room airflow distribution from the floor registers was done using a thermal imaging screen and infrared camera. In House 1, with stamped steel floor registers, vanes at a uniform 45°, tests during the cooling season showed significant stratification (4°F-5°F (2°C-3°C) between the floor and 7 ft (2.134 m) height with the supply air discharge essentially pooling at floor level, Figure 4.

In House 2, with a floor register that projected a narrower plume, cooling airflow extended farther up the wall under all flow conditions (this system was equipped with a zone control system so flow was variable). Yet, only at maximum flow (estimated to be in excess of the flow to typical rooms) was reasonable overall room mixing indicated with stratification of 3°F to 4°F (2°C to 3°C) between the floor and 7 ft (2.134 m) height (Figure 5).

The conclusions from this study are that floor registers, designed to spread the primary air, though excellent for the heating season, pose a challenge to good cooling performance. With excessive flow rates, they may be made to force mixing throughout the room. Floor distribution is thus neither efficient nor capable of providing good room comfort conditions through all heating and cooling seasons, unless seasonally adjusted, such as through the variation of flow pattern by the use of adjustable blades.

One of the most serious objections to the use of floor and baseboard diffusers is the potential for blockage. These diffus-

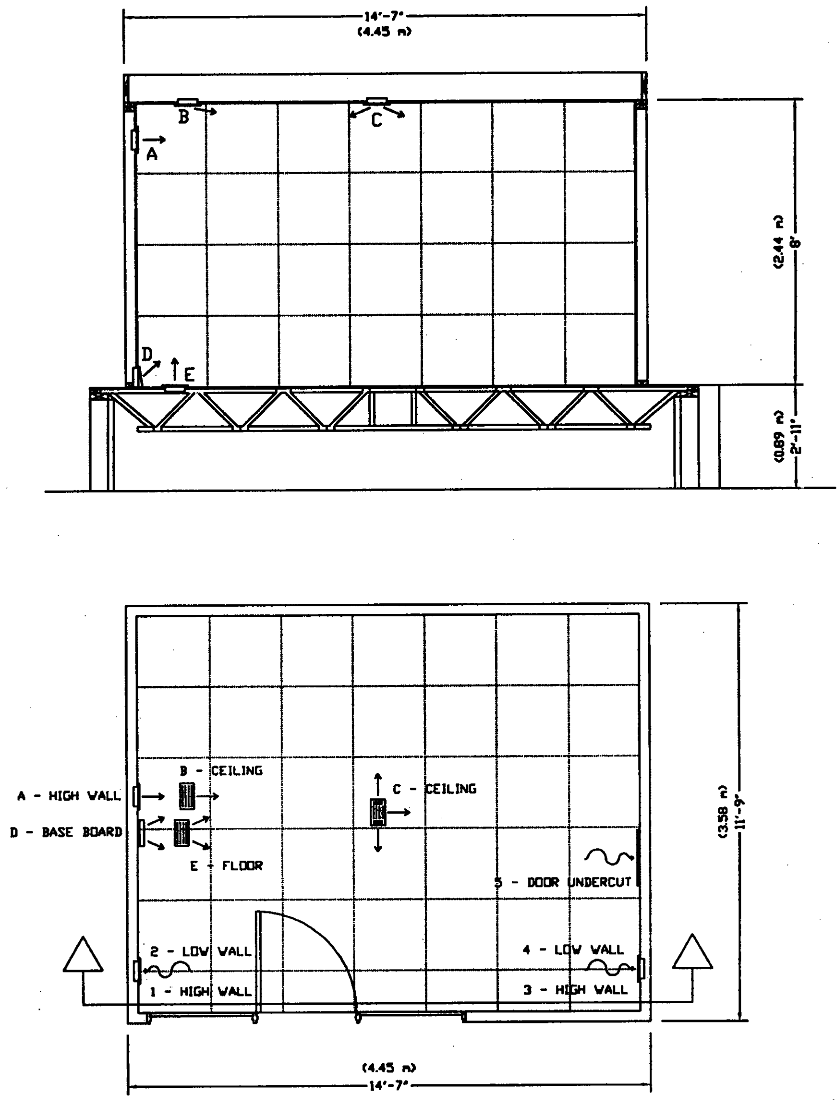


Figure 6 *Diffuser test facility.*

ers are located in portions of the room where they are routinely blocked by furniture and/or draperies. Indeed, the preferred location, directly below a window, practically ensures that the airflow will be blocked by floor length drapes or under window furniture.

TEST ROOM

In order to create a controlled and workable environment in which to experiment with a wide range of possible register designs and locations, a trial test chamber was constructed. This test chamber, representative of a typical mid-size room in a residence, is shown in Figure 6 (IBACOS 2000).

To this point, tests have been run on five different register types, at varying flow rates, under heating, cooling, or isothermal conditions, and with varying return locations. Initial evaluation of flow patterns was done with smoke injection, photography, and an array of surface temperature sensors. Later, five vertical temperature sensor arrays were erected in the room to evaluate in-room temperature uniformity of the occupied zone.

The surfaces of the room can be adjusted to the approximate conditions of the work area. During warm weather this may be in the high 70s °F (mid-20s °C). In cold weather it may be brought down to near 60°F (16°C). This gives some replication of what room surface temperatures and thus heating or chilling effects, acting on the supply air jet, might be under actual cooling or heating conditions.

Testing was done on each register. Parameters and results are shown in Table 1. What was sought was a throw pattern, as revealed by the injected smoke, which extended down the full height of the target wall (the window wall) under both heating and cooling conditions. This provided an indication that the

TABLE 1
Register Test Program Summary

Test no.	Register Type	Location	Mode	Airflows, cfm (L/s)	Adequate Throw	Stratification	Surface Chilling
1	commercial curved blade 1.5 × 18 (38 × 457 mm)	ceiling	adiabatic	—	—	—	—
			heating	82, 106 (39, 47)	yes	little	—
2	stamped steel 4 × 10 (102 × 254 mm)	floor	adiabatic	100 (47)	yes	little	no
			heating	100 (47)	yes	little	no
			cooling	100 (47)	yes	great	no
3	stamped steel baseboard	baseboard	adiabatic	100 (47)	no	little	no
			cooling	—	—	—	—
4	stamped steel two-way 6 × 10 (152 × 254 mm)	highwall	adiabatic	65, 100 (31, 47)	yes	little	no
			heating	65, 100 (31, 47)	no	great	no
			cooling	—	—	—	—
5	adjustable curved blade 4 × 8 (102 × 203 mm)	highwall	heating	100, 125 (47, 59)	no	great	no
			cooling	—	—	—	possible
6	adjustable curved blade 4 × 8 (102 × 203 mm)	ceiling	heating	100, 125 (47, 59)	no	great	no
			cooling	—	—	—	possible
7	2 in. nozzle (50 mm)	highwall	heating	60 (28)	yes	little	possible

airflow would address the primary load point of most rooms, the windows. Second, the uniformity of temperature throughout the occupied zone of the room, 0-6 ft (0-1.8 m), was an indication of good room comfort conditions. Third, the primary, discernable plume of supply air, heating or cooling, should not be in an area of the room that would impinge on occupants, i.e., below 6 ft (2 m). It should be above, or away from, the occupied zone until it is mixed with room air to a well-modulated temperature and velocity. Finally, during cooling, the primary plume should not cause overcooling of room surfaces. Consistent overcooling of gypsum board can reduce the surface temperature within the stud cavity to temperatures below representative hot-humid climate summer dew points (a measure of condensation control). Prolonged operation under these conditions promotes mold growth and can lead to water damage.

During the various supply register tests, the return location was varied from low wall to high wall. There was found to be little or no difference in room conditions with a change in return grille location. However, further testing is planned to evaluate the pressurization effect of varying the return size (i.e., when returns are undersized, excessive room pressurization may result).

A final component of this test and evaluation program was to assess the applicability of the design data provided by manufacturers. Performance data from five different manufacturers, for a common 4 × 10 (101.6 × 254 mm) floor register, one of which had been used in the test program, are presented in Table 2. It is instructive to look at a specific operating condition for a typical room, the introduction of cooling air from a floor register. To obtain an isothermal throw (measured to the 50 fpm [0.254 m/s] contour) of 8-10 ft (2.44 – 3.05 m), indicative of a probable throw that will eliminate pooling of cold air at the floor, could require from 120 to 173 cfm (56.6 – 81.64 L/s). The table indicates a wide divergence in performance characteristics for five registers that are usually considered to be the same. Without careful engineering of the duct and register assembly of a system, great differences in performance and room comfort could result.

OBSERVATIONS

It has become apparent from these investigations that a more effective approach to room air distribution is needed to match the characteristics of today's "better home." Current residential HVAC system design and construction techniques are inadequately matched to the higher performance levels expected from today's homes. Investigations seem appropriate to establish the technical parameters of suitable design and construction for today's "better home." Because these involve the interaction between rooms, registers, and HVAC systems, this is an area of investigation well suited to impartial, third party organizations. Such investigations might encompass the following topics:

1. Test room characteristics
2. Register types
3. Register locations
4. Throw/mixing/stratification
5. Air volumes
6. Air temperatures
7. Pressure drops
8. Seasonal changeover (airflow/throw changes)
9. Approach geometrics
10. Return locations and sizes
11. Condensation potential
12. Surface staining (entrainment)
13. Expanded performance parameters
14. Noise levels

Test Room Characteristics

Most research on registers and manufacturers' data has been based on commercial room sizes. Indeed, the standard for register testing, ASHRAE 70-1991 (ASHRAE 1991), specifies a room that is a minimum of twenty-four feet long, eighteen feet wide, and nine feet high. Using such dimensions misrepresents the surface effects of typical residential room sizes. Thus, an 11 ft × 14 ft (3.35 × 4.27 m) test room has been suggested as more representative. Another important parameter in the setup of the test room is room surface temperatures. Because surface effects and buoyancy are suspected to have substantial impact on the behavior of the supply airstream, it may be important to be able to replicate the warm surface of walls, windows, ceilings, and floors during cooling performance tests, and the reverse for heating performance tests. Ventilation flow tests might be conducted under heating, cooling, and swing-season (adiabatic) conditions to determine if there is any performance sensitivity due to room surface temperatures.

Register Types

With the lower airflows required to meet the reduced loads of the "better home," smaller registers and registers that provide better directional control may be appropriate. Thus testing may include adjustable blade registers, slot diffusers, and nozzles in addition to the more conventional stamped metal and plastic units typically employed in residential work. It may be appropriate to also look further into the range of components used in commercial HVAC design, such as variable-volume and temperature-variable diffusers that could offer improved performance through a range of operating conditions.

TABLE 2
Performance of 4 x 10 (102 x 254 mm) Floor Registers

Company	Throw (ft/m)	Spread (ft/m)	CFM (L/s)	Face Velocity, fpm (m/s)	Pressure Drop, in. water (Pa)
#1	9 ft (2.75 m)	11 ft (3.35 m)	120 (57)	700 (3.56)	0.030 (7.5)
#2	9 ft (2.75 m)	11 ft (3.35 m)	120 (57)	700 (3.56)	0.031 (7.7)
#3	9 ft (2.75 m)	13 ft (4 m)	140 (66)	736 (3.75)	0.037 (9.2)
#4	8 ft (2.5 m)	14 ft (4.3 m)	173 (82)	1000 (5.1)	0.082 (20.4)
#5	8.5 ft (2.6 m)	14 ft (4.3 m)	150 (71)	665 (3.4)	0.045 (11.2)

Register Locations

Current residential HVAC design typically will locate registers under windows in heating-dominated climates and in the ceiling in cooling-dominated climates. These locations respond to the heavy loads experienced in the average, thermally deficient home. The improved thermal envelope of the "better home" allows greater freedom of register location because there is not such a large loss/gain to overcome. With this freedom comes the ability to address other important location issues associated with register placement. In particular, it is now possible to remove registers from the floor or baseboard where there is a large probability of blockage. This one change should make a great improvement in the ability to ensure good comfort conditions in residences. Removing registers from the floor/ baseboard zone means they must be located in the high wall or ceiling. To minimize ceiling ductwork, which is often attic ductwork exposed to the extreme temperature conditions, the most desirable location for registers then becomes the high wall position. Thus, the initial focus of the research program should be in developing registers that can provide the desired air distribution throughout the room from a high wall location. This may include rear-wall and sidewall positions. The sidewall location also offers the opportunity to test designs located nearer or farther from an outside (window) wall.

To support the design of centerline duct systems, registers would be located near the inside wall of typical rooms. Thus, the ability of the register to provide a throw sufficient to cross the room and project down the outside wall would be of interest. Ceiling locations should also be evaluated as they can also be nearer, or further from, the outside (window) wall.

To address air distribution for high volume spaces, it would be desirable to test registers and nozzles for performance in projecting a free jet across a room. As well, tests of floor and baseboard registers should be included in the research program for comparison purposes.

Throw/Mixing/Stratification

These are seen, along with pressure drop, as the key performance parameters for measurement. In particular, a throw pattern that extends down/across/up the full dimension of the target wall (the window wall) would be indicative of good coverage of the primary load point of the room. The throw pattern should not intrude into the occupied zone of the room, as impingement of an airstream on room occupants would be uncomfortable.

Stratification of no more than 4°F (2°C) from floor to 6 feet (1.83 meter) height would seem a reasonable measure of good performance.

Air Volumes

This, along with temperature, is one of the key variables to be used in driving register performance. Investigations should include a range of supply air volumes that represent the expected change from cooling to heating season. Air volumes representative of the lower fan speed of a two-speed furnace should be evaluated (for this condition, the under window location does seem uniquely qualified).

Register performance, under conditions that represent the flow range experienced with zoning systems, should be evaluated. This may mean flows slightly above the usual maximum flow to volumes well below a low heating speed. Such a wide range could have strong design implications.

Ventilation volumes should also be evaluated, as HVAC central systems are often used as the distribution channel to ensure that fresh ventilation air is distributed to all occupied spaces in the house. With ventilation, good room air distribution is different from distribution to meet heating or cooling loads. Additional criteria for acceptable performance will need to be developed for ventilation-only flows. These flows may be quite small with registers performing more like a discharge port than a component capable of developing considerable throw. Ventilation effectiveness would seem to be an important parameter.

Commercial approaches to variable volume control would be worthy of investigation to see if the benefits were significant. If they were, it might be practical to suggest simplified approaches to volume control that would be suited to a residential market.

Air Temperatures

The applicable standard for testing registers, ASHRAE 70-1991 (ASHRAE 1991), is fundamentally an isothermal test, though some description is given for testing with cold air. It states that room temperature be maintained between 68°F and 82°F (20°C and 28°C), a wide range. It does not discuss testing for heating conditions nor control of room surface temperatures.

Because buoyancy effects can be so influential on the travel of an air plume, particularly at its outer edges where momentum is low, testing with surface temperatures representative of heating or cooling climatic influences may be important. This may particularly be the case with the reduced airflows of the high performance house.

A range of supply air temperatures should be used in investigations:

1. cooling
2. ventilation
3. heating to heat pump levels (or low-fire furnace levels)
4. full furnace levels

In all cases, room surfaces should be tempered to represent real-world conditions during similar outdoor conditions.

Commercial approaches to temperature-variable volume control might also be investigated for possible beneficial performance effects by observing mixing and throw at various temperatures.

Pressure Drops

With centerline duct design, registers are located in or near inside walls and must throw primary air to the outside of the room to achieve good mixing. This may require greater pressure drops across the register than with low throw designs. Also, with the low flows associated with ventilation, pressures may be so reduced that well-controlled discharge from a register is not possible. Thus, pressure drop is a key parameter to evaluate in any test program and has implications for duct system design and even blower, cabinet, and motor design. There are possible energy penalties as well. Trade-offs between register throw and spread need to be evaluated in terms of occupant comfort.

An objective of the centerline duct design approach and the optimum register selection would be to achieve good comfort conditions in the room at reduced distribution energy use.

Seasonal Changeover

Because no single location and register combination is ideal for both heating and cooling, there may be advantages to development of a simple, reliable means of altering the throw pattern of registers on a seasonal basis to favor heating or cooling performance. Such variation might be accomplished by manual or temperature-activated automatic means. The program should evaluate these approaches.

Approach Geometries

When seeking to improve the performance of supply registers the geometry of the ductwork that leads the air into the register may play an important role. Current boot designs are crude and are configured, to a considerable degree, to simplify fabrication from sheet metal. Optimized designs that employ flow straightening, including smoother contours and turning vanes, may be quite beneficial in achieving good airflow with low-pressure drop. Tight 90° turns into the register, such as used for high wall and several other locations, may be valuable to investigate. Additionally, new boot designs should provide leak-free connections to the register and duct, thus remedying one of the major sources of in-house duct leakage.

Return Locations and Sizes

For a given room there are several possible return air approaches: individual return ducts to the central system, transfer grilles or ducts to an adjacent space, or a door undercut to transfer to an adjacent space. Both location and size of return are variable. Tests should be conducted over the range of these variables under heating, cooling, and ventilating conditions. The effects to be measured would include room temperature uniformity, ventilation distribution, and room pressurization.

Condensation Potential

When evaluating cold air delivery to a room, condensation potential is an issue. Condensation damage on the backside of ceiling gypsum board due to register airflow patterns in the occupied space has been observed. Thus, register tests should evaluate backside surface temperatures as developed by different register flow patterns.

Surface Staining

A problem sometimes exhibited in commercial diffuser installations is surface staining immediately adjacent to the diffuser. This is usually associated with diffusers that entrain a large proportion of room air into their flow pattern. It is often also associated with heavy smoking environments. However, as new register performance is developed for residential applications, this characteristic should not be overlooked. Throw patterns that rely on the "Coanda effect" to develop attachment to a ceiling or wall surface may induce more dirt build-up on these surfaces than more free flow discharge patterns. Comparative, accelerated testing might be a way to evaluate this characteristic.

Expanded Performance Parameters

Current manufacturers' data are not adequate to support proper design of register applications for the "better home." Additional parameters are desirable. At a minimum, these would include throw, drop, and spread ratings under heating, cooling, and isothermal conditions.

Noise Levels

Though this aspect of performance is generally only assessed for commercial diffusers, the greater throw and directional control that are anticipated to be key attributes of registers in the "better home" suggests that noise levels should be assessed in conjunction with other aspects of register performance.

CONCLUSIONS

Experience in the Building America program with homes built to greatly improve thermal performance standards has revealed the shortcoming of using "old" HVAC system design and construction approaches on "new" houses. Field and test chamber investigations have detailed some of these deficiencies and have led to the formulation of a proposed assessment approach for residential registers. The fourteen elements of this approach should make a significant contribution to the development of high performance residential air distribution systems. It should also provide guidance for the development of appropriate performance parameters to be used in the design of such systems.

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